

BMJ Open Is a novel diagnostic pathway for cardiology outpatient clinics in Singapore lower cost than existing practice: a cost modelling study

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ABSTRACT

Objective To evaluate the potential for change to costs from a decision to adopt a novel diagnostic pathway for referrals to cardiology outpatients with symptoms of chest pain.

Design Costs modelling study using existing observational data, with a cost year of 2018.

Setting Specialist Heart Centre in Singapore.

Participants All new referrals (n=10 622) to the outpatient clinics for investigation between January 2017 and December 2017.

Interventions Two competing testing regimes are compared in a decision tree model. Current practice includes classification of patients by their risk and the use of treadmill tests, calcium scores, functional testing and CT angiogram. New practice offers a fundamental difference in use of diagnostics for patients, with some offered angiogram directly and for low-risk patients a calcium score is used to refine risk stratification.

Outcome measures The expected cost difference between testing alternatives.

Results The expected cost saving from 'New Practice' as compared with 'Current Practice' is \$S764 per patient. There is a 50% probability the savings per patient range between \$S764 and \$S824 and a 90% probability they are between \$S616 and \$S912. The expected savings to Singapore national health services are \$S26.8 million annually, with a range of \$S16.2 to \$S41.1 million.

Conclusions We find some evidence that using a coronary calcium score, which can be performed with a fraction of the time and cost of a CT coronary angiogram, saves costs to health services.

Strengths and limitations of this study

- We use existing data to model whether costs are likely to be reduced from adopting a novel diagnostic pathway in cardiology outpatients.
- The range of costs included in the analysis are limited with only the health services perspective included.
- There is no assessment of mortality risk or health-related quality of life.
- The cost savings only reflect historic expenditures on mostly fixed costs.
- The presentation of cost savings might not indicate the cash released from adoption.

with Australia.³ Prolonged growth in health-care spending is, however, not viable with many high-income countries now making strenuous efforts to control costs.⁴ The Singapore government has specific policies for cost control that combine individual responsibility with government subsidies for primary health services.³ To complement this top-down regulation every opportunity to slow cost increases should be taken by relevant stakeholders including service providers.

In 2017, approximately one-third of all years of life lost in Singapore were to cardiovascular diseases, second only to cancer.⁵ Around 70 000 new cases are referred to cardiology specialist clinics per year, with 30 000 new cases per year referred to the National Heart Centre of Singapore. Approximately 50% of referrals have symptoms of chest pain that require diagnostic testing to rule out significant coronary artery disease.⁶ It seems useful to consider lower cost options for these testing and diagnosis activities.⁷

An optimal strategy to diagnose and manage chest pain is still under debate. Large randomised trials in recent years have addressed the concept of anatomical testing using the CT coronary angiogram. This is

INTRODUCTION

Between 2000 and 2016 spending on health services in Singapore increased by 300%.¹ An ageing population is one reason and this pressure will remain with an expected 137% increase in those >60 years by 2050.² Other factors that increase costs are the adoption of novel medical technology and new pharmaceuticals. Comparatively, these cost increases are from a low base with Singapore spending approximately half the proportion of gross domestic product on healthcare as compared



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compared with traditional functional testing to detect ischaemia through exercise or pharmacological stress imaging tests. The SCOT-HEART study investigated the effectiveness of adding CT coronary angiogram to standard care, which comprised treadmill testing in 85% of the patients in both the routine care arm and the CT coronary angiogram arm.⁸ There was a meaningful reduction in risk of myocardial infarction and stroke for the standard care plus CT angiogram arm, compared with the standard care arm, with equivalent rates of revascularisation in both arms. The reduction in major adverse cardiovascular events in the SCOT-HEART trial was attributed largely to an increase in medication for risk factor control based on information obtained from the CT coronary angiogram, where the presence of atherosclerosis can also be obtained from a CT calcium score, which requires less radiation. A meta-analysis⁹ concluded that compared with functional testing, coronary CT angiography appeared to reduce the incidence of myocardial infarction, but not death nor cardiac hospitalisations. It was noted that extra cost arose from increased downstream rates of invasive coronary angiography and coronary revascularisation. The reduction in myocardial infarction was largely driven by the evidence from SCOT-HEART.⁸

These findings encouraged the team to propose a new testing pathway to reach a safe threshold to exclude coronary artery disease and combine functional and anatomical stress testing using a calcium score instead of a full dose CT coronary angiogram. Findings from the coronary calcium score can prompt physician prescriptions for aspirin and statin medications, to reduce myocardial infarction rates.¹⁰

The major idea to be evaluated for this paper is that the coronary calcium score, which can be performed with a fraction of the time and cost of a CT coronary angiogram, can provide information to guide medication prescription that is comparable to CT coronary angiogram. Indeed, based on local data the net reclassification index of adding a calcium score to patient chest pain history demonstrates a net reclassification index of 46.5% in predicting CT-detected coronary artery stenosis.¹¹

From a clinical perspective, a zero calcium score confers good prognosis for chest pain with a ~1% annual event rate¹² despite the small risk of non-calcified plaques.¹³ A non-zero calcium score provides an opportunity for the initiation of statins, especially in those aged 55 and above or with an increased Atherosclerotic Cardiovascular Disease score, as recommended by the 2018 American College of Cardiology and American Heart Association cholesterol Guidelines.¹⁴ Even in younger patients where the utility of CT calcium score is less clear, there is growing evidence to show that the presence of coronary atherosclerosis have significantly higher risk for cardiovascular mortality.^{15–17} Where the calcium score is >100 there is evidence to support the prescription of aspirin for primary prevention.¹⁸ The radiation dose of a coronary calcium score is at least three times lower than the CT coronary angiogram.¹⁹ Coronary calcium scoring has

equivalent radiation similar to the level of background radiation exposure experienced over 3–4 months in most cities and the risk of such low dose radiation exposure remains speculative.²⁰

Current testing regimens in Singapore are based on guidelines from the American College of Cardiology and Europe Society of Cardiology.^{21 22} These allow for considerable variation for the investigation of chest pain. The multiple methods available for evaluating patients have led to variation in physician practice, plausibly influenced by fear of medicolegal events and so defensive medicine arises.

The aim of this study is to evaluate the expected changes to costs as compared with current practice from a decision to adopt a novel diagnostic pathway implemented at the Cardiology Outpatient Clinic at the Singapore General Hospital. This is a cost modelling study that only considers changes to costs. The analyses might be used to support changes to an institutional protocol suitable for the Singapore setting.

METHOD

We estimate the cost outcomes arising from two competing testing regimes as applied to modelled cohorts of patients who present at the outpatient's department with unspecified chest pain. The perspective of the health services is adopted for the cost analysis and the cost year is 2018. Costs are considered within 1 year so discounting is not used.

Setting

The setting is the department of cardiology at the National Heart Centre Singapore at SingHealth, which has 180 inpatient beds. Family physicians and community-based polyclinics refer patients to National Heart Centre Singapore for further management of heart related diseases and non-emergent, stable patients are evaluated at specialist outpatient clinics. The approaches used to assess patients and the methods of intervention vary considerably with physician.

Competing alternatives, model structure and data used

Two competing testing regimens are included in a decision tree model programmed in, TreeAge Pro 2021 R1.2.²³ The 'Current Practice' comparator includes the classification of patients by their risk based on treadmill tests, calcium scores, functional testing and CT angiogram. While 'New Practice' offers a fundamental difference in use of diagnostics for patients with some offered angiogram directly and for the low risk group a calcium score is used sooner to refine risk stratification. Investigations of coronary artery disease are broadly divided into: anatomical testing, which includes CT coronary angiogram, CT coronary calcium scoring, invasive coronary angiography; and, functional stress testing, which includes treadmill and dobutamine stress echocardiogram, myocardial perfusion imaging and adenosine stress cardiac MRI. For

Table 1 Demographics and test utilisation of outpatients presenting with chest pain

	All patients (n=10622)	Low-risk patients (n=3667)*	Elevated risk patients (n=6995)*
Age (years)	58.0±13.4	47.3±12.7	63.6±9.9
Male (%)	5848 (55.0)	798 (21.7)	5050 (72.6)
Diamond-Forrester Score (%)	19.3±15.6	5.5±2.4	26.7±14.6
% of patients underwent functional test†	8112 (76.3%)	2628 (71.6%)	5484 (78.8%)
Stress echocardiogram (dobutamine/exercise)	3827 (47.2%)	1741 (66.2%)	2986 (38.0%)
Myocardial perfusion imaging	4387 (54.1%)	902 (34.3%)	3485 (63.5%)
Treadmill exercise test	136 (1.7%)	73 (2.8%)	63 (1.1%)
Adenosine stress cardiac MR	10 (0.1%)	5 (0.2%)	5 (0.1%)
% of patients underwent CT coronary angiogram	1165 (10.9%)	437 (11.9%)	728 (10.4%)
% of patients underwent CT coronary calcium scoring	476 (3.5%)	172 (4.6%)	204 (2.9%)
Total no of tests per patient is 1	8896 (83.7%)	3315 (90.4%)	5581 (80.2%)
Total no of tests per patient is 2	906 (8.5%)	329 (8.9%)	577 (8.3%)
Total no of tests per patient is 3	48 (0.4%)	19 (0.5%)	29 (0.4%)
% underwent coronary angiogram	1795 (16.9%)	155 (4.2%)	1640 (23.5%)
% underwent intervention/bypass surgery	982 (9.2%)	42 (1.1%)	940 (13.5%)
Myocardial Infarction	46 (0.4%)	4 (0.1%)	42 (0.6%)

*Low-risk patients are defined as Diamond-Forrester pretest probability <10%; elevated risk patients are defined as Diamond-Forrester pretest probability >10%.

†Functional tests include treadmill exercise test, treadmill or dobutamine stress echocardiogram, myocardial perfusion imaging and adenosine stress cardiac MRI. Patient may undergo >1 test.

the purpose of this study, 'functional stress testing' in the 'New Practice' refers to treadmill and dobutamine stress echocardiogram and myocardial perfusion imaging. Adenosine stress cardiac MR although available in our centre, is costlier more time-intensive and usually does not provide additional diagnostic benefit.

Information on the probabilities of competing events arising in the model were obtained from deidentified administrative database of all new referrals (n=10622) to the National Heart Centre Singapore outpatient clinics for investigation between January 2017 and December 2017. See [table 1](#) for some summary statistics of these individuals. The type of tests ordered is based on physician preference and discretion during the clinic encounter.

The costs of the tests used for the decision tree outcome are shown in [table 2](#). The summary statistics were provided by the administration department of the National Heart Centre of Singapore and represent accounting costs for

2018 designed to keep the institution solvent, they may, therefore, diverge from true economic opportunity costs.

The components and ordering of 'Current Practice' are shown in [figure 1](#). Patients are categorised as requiring, or not, further testing using the Diamond-Forrester Score.²⁴ Risk categories of <10% represent low-risk patients which do not require further testing based on society guidelines,²⁵ while symptomatic chest pain patients with risk scores ≥10% may warrant further testing. The subsequent pathways of test utilisation follow the physician choices made in clinical practice. The values for the parameters that inform the probabilities of the events in [figure 1](#) are shown in [table 3](#).

For the proposed 'New Practice' patients are divided into two distinct pathways or offered angiogram directly, see [figure 2](#) and [table 4](#) for the parameter values used. The decision for the choice of initial testing is based on the distribution of risk from the Diamond-Forrester Score

Table 2 Cost information used for both parts of the model

Variable name	Description	Mean (SD)	Distribution
D_C_Angio	Cost of angiogram	\$S5000 (408)	Gamma (150, 33.33)
D_C_CalTest	Cost of calcium test	\$S550 (45)	Gamma (150, 3.67)
D_C_CTAngio	Cost of CT angiogram	\$S1304 (106)	Gamma (150, 8.68)
D_C_MyocardialP	Cost of myocardial perfusion	\$S994 (81)	Gamma (150, 6.63)
D_C_StressEcho	Cost of stress echo	\$S772 (63)	Gamma (150, 5.15)
D_C_TreadmillTest	Cost of treadmill test	\$S336 (27)	Gamma (150, 2.24)

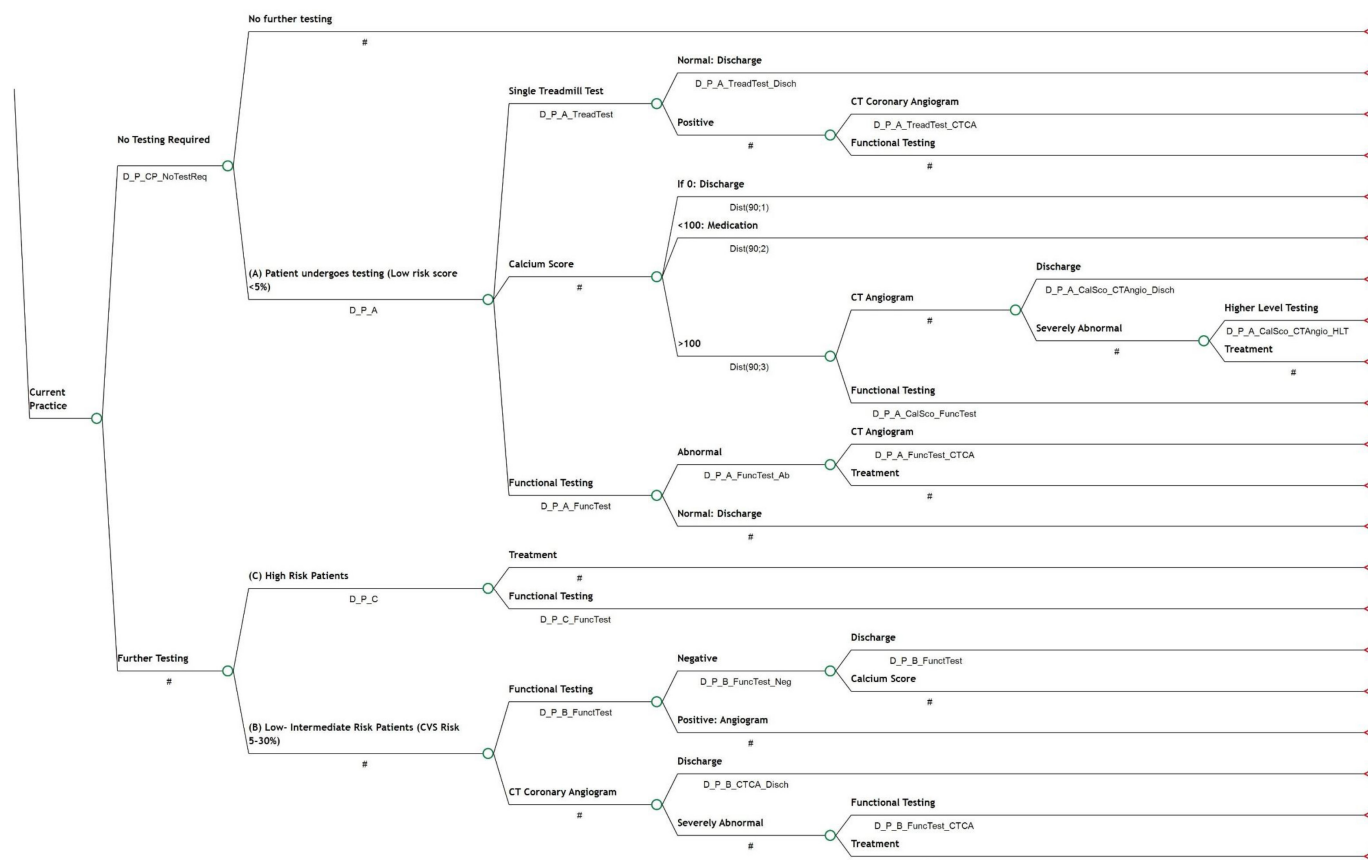


Figure 1 Current practice testing. CTCA, CT coronary angiogram ; #, one minus the value of the other probability emanating from the circular chance node

obtained from the retrospective administrative database. The distribution of the outcomes of tests are based on the historical outcomes in that risk range determined by the Diamond-Forrester Score. Since society guidelines recommend no further testing when the probability of coronary artery disease is $<10\%$,²⁶ the 'New Practice' follows this principle to reduce the Diamond-Forrester pretest probability to $<10\%$ based on published sensitivities and specificities of both anatomical and functional stress tests,²⁷ before safely excluding coronary artery disease. This can be done by either one test or a series of tests.

Model evaluation

The expected cost outcomes for an average patient undergoing each competing testing regimen were calculated by multiplying the cost outcome by the probability they arise. Prior distributions are fitted to parameters using either a gamma, beta or Dirichlet²⁸ and five thousand random picks made from all model parameters using Monte Carlo simulations. This generates a distribution of expected cost outcomes for each testing strategy. The distribution of the incremental difference in cost between the two testing approach is the primary outcome. The total number of patients at SGH and nationally eligible for either current practice or the new practice alternative is estimated to be 50% of 30 000 and 70 000, respectively. The time horizon is short, pertaining to the initial testing

done for cardiology outpatients, and is approximately 3 months at a maximum.

Patient and public involvement

There was no patient or public involvement in this research. We only used routinely collected and summary information about the types of tests patients had in cardiology outpatients. All data were anonymous and deidentified.

RESULTS

The expected per patient costs for both testing approaches is shown in table 5.

The mean incremental cost difference is \$764 per patient with new practice representing the lower cost option. The distribution of the expected incremental cost savings per patient is shown in figure 3. There is a 50% probability the expected cost saving per patient are in the range between \$764 and \$824 and a 90% probability they are between \$616 and \$912. Because all 5000 simulations take a value less than zero we interpret the findings as 100% certain that adopting new practice over old practice will save costs. The expected savings to SGH annually would be \$11.5 million (range \$6.9–\$17.6) and nationally the expected savings would be \$26.8 million (range \$16.2–\$41.1).

Table 3 Parameters for figure 1 that describe current practice

Name of parameter	Description of parameter	Mean	Distribution
D_P_CP_NoTestReq	Probability for current practice of no testing required	34.52%	Beta (3667, 6955)
D_P_A	Patients who underwent testing despite risk score of 5% and not indicated in A	90.00%	Beta (90, 10)
D_P_C	Probability of patients with high risk of CVS	32.34%	Beta (2249, 4706)
D_P_A_TreadTest	Probability of patients in A who underwent treadmill test	21.09%	Beta (773, 2893)
D_P_A_FuncTest	Of no of patients in A who underwent functional testing	69.68%	Beta (2555, 1112)
D_P_C_FuncTest	Probability of patients in C who underwent functional test	70.30%	Beta (2249, 950)
D_P_B_FunctTest	Probability of patients in B who underwent functional test	84.85%	Beta (4078, 728)
D_P_A_TreadTest_Disch	Probability of patients in A who underwent Treadmill Test and were discharged	84.73%	Beta (655, 118)
Calcium Score, three outcomes	0, <100 or >100	30.4%, 28.1%, 41.5%	Dirichlet (1044, 963, 1424)
D_P_A_FuncTest_Ab	Probability of patients in A who underwent Functional Test return Abnormal	25.01%	Beta (639, 1916)
D_P_B_FuncTest_Neg	Probability of patients in C who underwent functional test and tested negative	88.45%	Beta (3607, 471)
D_P_B_CTCA_Disch	Probability of patients in B who underwent CT coronary angiogram and were discharged	75.00%	Beta (75, 25)
D_P_A_TreadTest_CTCA	Probability of patients in A who underwent treadmill test and CT coronary angiogram	38.14%	Beta (45, 73)
D_P_A_CalSco_FuncTest	Probability of patients in A who underwent calcium score and functional test	15.93%	Beta (54, 285)
D_P_A_FuncTest_CTCA	Probability of patients in A who underwent functional test and CT coronary angiogram	4.50%	Beta (115, 2440)
D_P_B_FuncTest_CTCA	Probability of patients in B who underwent functional test and CT coronary angiogram	4.06%	Beta (295, 6978)
D_P_A_CalSco_CTAngio_Disch	Probability of patients in A who underwent Calcium Score and CT angiogram and were	91.23%	Beta (260, 25)
D_P_A_CalSco_CTAngio_HLT	Probability of patients in A who underwent Calcium score and had a severely abnormal CT Angiogram and underwent higher level testing	16.00%	Beta (4,21)

DISCUSSION

This analysis reveals some potential for cost savings from a decision to change the way patients referred to cardiology specialist clinics in Singapore are tested. Rather than use existing international guidelines, that enable diverse approaches among clinicians, we modelled an evidence-based alternative that relies on a coronary calcium score to inform risk assessment and subsequent decision making. Our primary conclusion is that patient safety could be maintained while saving resources and costs. This work will be useful for stakeholders interested in containing costs to Singapore health services and there exists potential to update this analytic model with data from other jurisdictions.

This is, however, a modest study with limitations. We use existing data with the anticipation of improving clarity about the value of a future clinical trial, which might address this question with fewer caveats. Sustained implementations of change to clinical practices require a strong base of evidence²⁹ and this analysis provides partial evidence only. A future randomised clinical trial might select outcomes and endpoints that will resonate with clinicians, it might be pragmatic and established in the normal practice setting with a full range of study participants, in contrast to an idealised of highly controlled setting with strict protocols and quality checks with a highly selected group of patients.³⁰ It might also be powered for the needs of decision makers in mind, rather

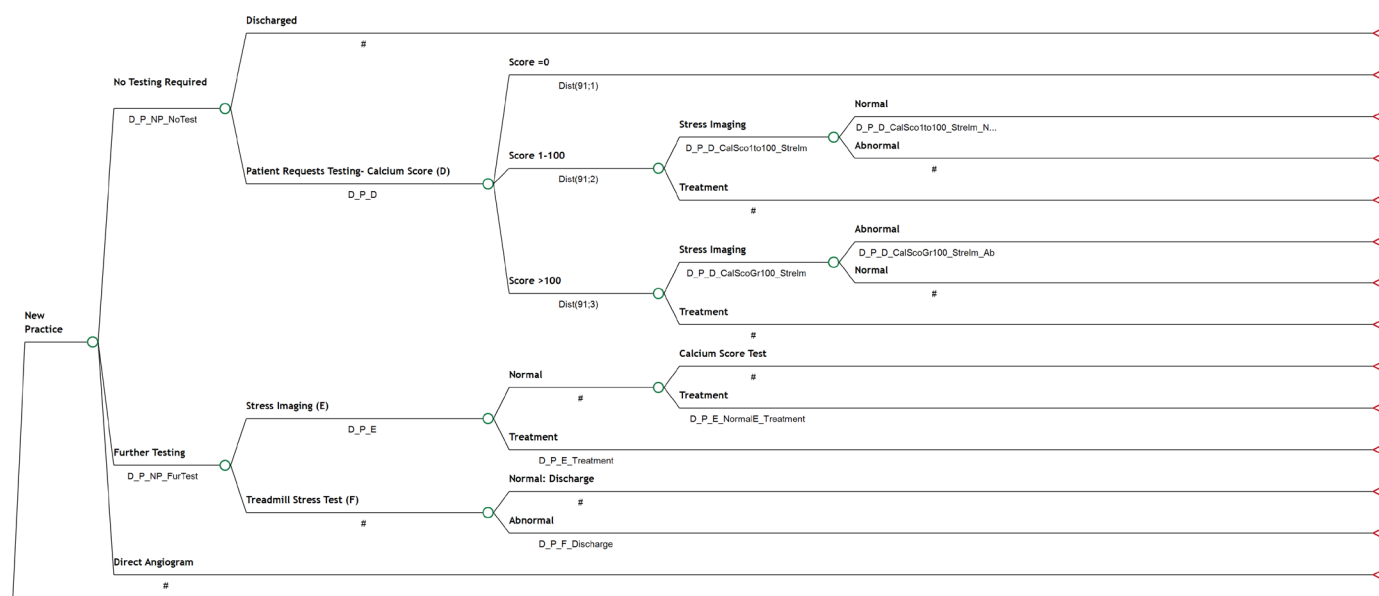


Figure 2 New practice testing. #, one minus the probability attached to the other event emanating from the circular chance node.

than following the arbitrary conventions of hypothesis testing.³¹ Traditional sample size calculations do not consider the marginal value of the information collected for decision making, and the statistical hypothesis testing objective is misaligned with the goal of generating information necessary for decision-making.³² No information is reported on health outcomes in this ‘costs only’ analysis. In addition, the range of costs included is limited with only the health services perspective included. While arguments have been made, and some evidence provided, that decision making based on risks will be similar in both

options, there is no formal assessment of mortality risk or impact of health related quality of life. If a prospective trial were conducted, then these outcomes should be included. The synthesis of the evidence used is ad hoc, rather than based on protocols typically seen in systematic reviews. And a good amount of expert opinion and judgement has been used. Yet the assumptions made are transparent and the clinical authors have good knowledge of cardiology practice and the current evidence based. Another major limitation is the nature of the proposed cost savings. As most of the costs of providing

Table 4 Parameters for figure 2 that describes the new practice model

Name of parameter	Description of parameter	Mean	Distribution
D_P_NP_NoTest	Patients under new practice that do not require testing	54.41%	Beta (1914, 1604)
D_P_NP_FurTest	Patients under new practice that require testing	40.28%	Beta (1417, 2101)
D_P_D	Probability of patients in D who requests testing and get calcium tests	90.00%	Beta (90, 10)
D_P_E	Probability of patients in the new practice who required further testing and underwent stress imaging	90.00%	Beta (90, 10)
Calcium Score, three outcomes	0, <100 or >100	64.3%–24.2% 11.5%	Dirichlet (1169, 441, 209)
D_P_E_Treatment	Probability of patients in E who had treatment	32.50%	Beta (325, 675)
D_P_F_Discharge	Probability of patients in F who were discharged	32.50%	Beta (325, 675)
D_P_D_CalSco1to100_StreIm	Probability of patients in D with a calcium score of 1–100 who underwent stress Imaging	50.00%	Beta (50, 50)
D_P_D_CalScoGr100_StreIm	Probability of patients in D with a calcium score of greater than 100 who underwent stress Imaging	90.00%	Beta (90, 10)
D_P_E_NormalE_Treatment	Probability of patients in E who had normal outcomes and then treatment	53.96%	Beta (613, 523)
D_P_D_CalSco1to100_StreIm_Norm	Probability of patients in D with a calcium score of 1–100 with normal stress imaging	80.5%	Uniform (0.74, 0.87)
D_P_D_CalScoGr100_StreIm_Ab	Probability of patients in D with a calcium score of >100 who underwent stress imaging and it was abnormal	44.5%	Uniform (0.43, 0.46)

Table 5 Summary statistics for the expected cost per patient from new and current testing

\$S	Mean (SD)	95% uncertainty interval
Current practice	1717 (81)	1561 to 1882
New practice	951 (69)	823 to 1087

healthcare are fixed or sunk in the short run³³ a reduction in the use of tests might not release cash of a value that matches the estimates reported here.³⁴ Rather it is likely that the capacity of staff, equipment and healthcare capital resources are available for other testing indications, or there may be a reduction of the wait time to testing, as well as less pressure to increase capacity in response to waiting time. Finally, we did not include the likely costs of changing practices. Effective implementation of new models of care require some large effort of individual's time and often other resources to make them sustainable.³⁰

On a positive note the cost-effectiveness of testing in cardiology has received a lot of attention in the literature with systematic reviews and economic evaluations published about screening for atrial fibrillation,³⁵ cardiac MRI for ischaemic cardiomyopathy,³⁶ genetic testing for long QT syndrome³⁷ and for familial hypercholesterolaemia,³⁸ point-of-care tests for self-monitoring of coagulation status of people receiving long-term vitamin K antagonist therapy³⁹ and the use of high-sensitivity troponin assays for the early rule-out or diagnosis of acute myocardial.⁴⁰ We can find little evidence that compares the cost outcomes arising from the two models of testing presented here. Furthermore, other research⁴¹ shows there could be large opportunity costs from postponing the adoption of a new clinical practice whose benefits are uncertain. Prior studies at our institution have demonstrated feasibility of the calcium score in detecting obstructive coronary artery disease. At a cut-off of 100, the sensitivity, specificity and negative predictive value for detecting obstructive coronary artery disease were 73.2%, 84.8% and 94.8%, respectively. So for early adopters and

those motivated to make this kind of practice change, this analysis is valuable.

Finally, although the utility of CT calcium score in younger age groups below 50 years is less clear, there is growing evidence to show that the presence of coronary atherosclerosis have significantly higher risk for cardiovascular mortality.^{15–17} While the guidance for medication and treatments is less compelling in this age group, physicians can discuss the findings with patient and have a shared plan. Selective use of screening for CAC might be considered in individuals with risk factors in early adulthood to inform discussions about primary prevention.

Contributors NG conceived the study, interpreted the results and wrote early drafts of the paper; GK made the TreeAge model, populated it with data, ran multiple analyses and contributed to early drafts of the paper; HW and TC advised on study design, model structure and contributed substantially to the writing of the final paper; NG is overall guarantor of content.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Ethics review from SingHealth was not required due to the nature of deidentified administrative dataset. There were no patient identifiers that allowed the study team to retrospectively contact the patients and seek consent. It was also impractical due to the large sample size. Ethics review from NUS was not required as no patient level information was used for the final model analysis, rather summary outcomes such as probabilities of events were only used.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

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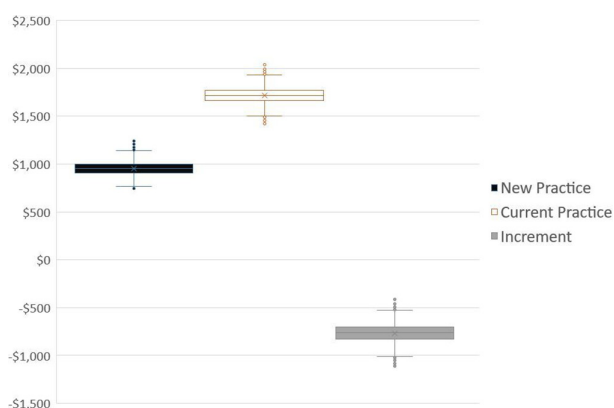


Figure 3 Distribution of the incremental change to cost outcomes.

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